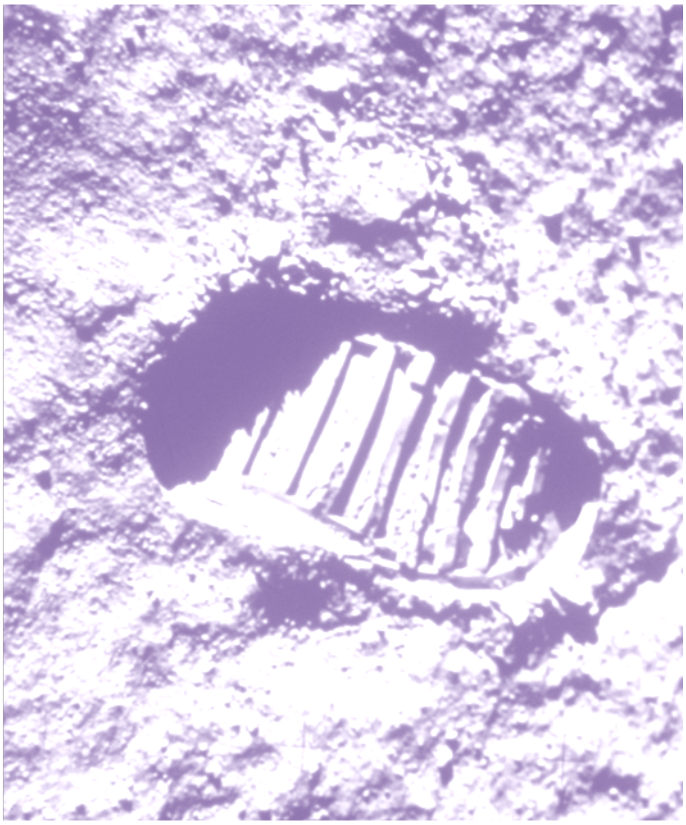
One Small Step for Schools, One Giant Leap for Gifted Education

Implementation of a problem based, cooperative learning, science curriculum



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Abstract

This article depicts how, over a period of one year, both teachers and gifted students of a Dutch secondary school tried to find their way in an educational method constructed around Problem Based Learning (PBL) and Cooperative Learning (CL).

For the science curriculum the so-called 'Design-based Learning' concept developed by Eindhoven University of Technology was adjusted to the specific situation at school. At the heart of this Design-based Learning lie PBL and CL, since problem solving and cooperation are thought to be of high value in today's research and development practice. The goal of this project was to see if Design-based Learning could be translated to a problem based, cooperative learning science curriculum for secondary school gifted students.

The teachers were instructed and trained before the start of the school year. During the school year, teachers and students were observed and questioned about their efforts and the outcomes.

The cooperative learning approach was appreciated by all students, even though they acknowledged the difficulties of being dependent on someone else and having to negotiate and compromise. But they need help with this; feedback by the tutor and the teacher on their teamwork skills is important and necessary.

The problem based approach proved to be much more difficult for the teachers than it was for the students. The teachers had to reinvent their way of teaching. Some succeeded better than others. PBL is so fundamentally different from traditional teaching that it is almost impossible for them to change autonomously. They will need more help with this the first coming years. They can turn to each other or they might want to think about a mentor for themselves.

For the students PBL was less of an obstacle, but they too had some changes to make. They needed a wake-up call: this is school ”not-as-you-know-it”, take your opportunity to learn and explore, not just sit and wait for the right answers to be given by the teacher!

This was not a one-year-success story, but it turned out well. An educational transformation like this takes time, years even. Teachers have to learn to let go and trust, to take a step back. Students will have to learn to take a step up and take the opportunity to shape their own education.

Introduction

> *The principal goal of education in the schools should be creating men and women who are capable of doing new things, not simply repeating what other generations have done; men and women who are creative, inventive and discoverers, who can be critical and verify, and not accept, everything they are offered.*
> (Piaget, quoted in Jervis & Tobier, 1988)

Whether or not these words by Piaget were actually known, they are in accordance with the intention of the Design-based Learning concept the Eindhoven University of Technology launched in September 1997: to educate students to become critical, analytical, skillful and creative engineers (Wijnen et al., 2000). Design-based Learning (DBL) had its base in Problem Based Learning (PBL) and was adjusted to function within an engineering context (Perrenet et al., 2000). Students are motivated to work cooperatively on real-world problems and to come up with inventive solutions, integrating knowledge from various disciplines (Wijnen et al., 2000).

When confronted with the question from teachers at a Dutch secondary school (the St. Willibrordgymnasium in Deurne) how to shape the science curriculum for their gifted first graders, this DBL-concept came to mind.

Piaget's words at the start of this introduction might be true for all students, they may apply especially well to gifted learners (Gardner, 2008; Renzulli, 2005; Schiever & Maker, 2003[1]). Does PBL match with gifted education? And what about gifted students working cooperatively on projects? Could the university concept of Design-based Learning be translated into a science curriculum for gifted secondary school students? A descriptive study around these main topics was born.

What does 'gifted' mean?

At the base of the term 'gifted' lies the concept of 'intelligence'. Spearman (1904) defined a general intelligence factor g, but in more recent decades the definition of intelligence broadened and researchers tried to identify different types of intelligence. Gardner (1993) was very successful with his theory of multiple intelligences. Sternberg (1985; 2003) proposed a trichotomy. His triarchic theory of intelligence involves analytical, practical and creative or synthetical intelligence. Recently the idea of intelligence not being a static given, but rather some trait that can be developed, grows in popularity. Gardner's and Sternberg's theories are congruent with this idea, but also research on the influence on learning of a fixed versus a growth mindset (Dweck, 2000), and the description of desirable habits of mind (Costa, 2007) endorse this.

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[1] This is an interpretation by the author of this article of some statements from leading 'gifted education' researchers. Specific quotes can be found in Appendix 2.

Despite numerous definitions of and theories about intelligence, standardized intelligence tests have been developed that conform to a Gaussian distribution of IQ among the general population (Brysbaert, 2006). Approximately 68% of all people have an ‘average IQ’ around 100; 2.5% have an IQ above 130 (see figure 1, Resing & Blok, 2002).

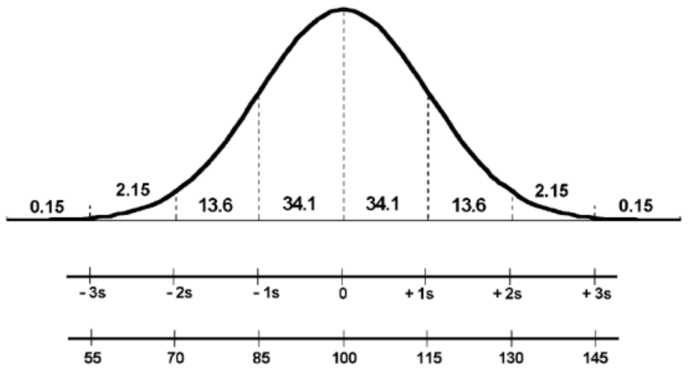

Figure 1. Gaussian distribution of IQ-scores

Often, an IQ threshold (usually in the 130 range) is chosen to define giftedness, but just as is the case with defining ‘intelligence’, there are also votes to broaden this definition.

A well-known and well-used definition of giftedness is that of Renzulli (1978; 2003). According to his three ring model of giftedness, a gifted person has above average intellectual capacities, is a creative problem solver and has the ability to commit to a task. Mönks (1988) added three environmental factors (family, school and peers) to Renzulli’s model. Although there is still discussion about the influences of nature and nurture on intelligence, many models on giftedness incorporate both components as a factor to be reckoned with (Tannenbaum, 2003; Heller, 2004; Gagné, 1985/2008).

It’s difficult to describe exactly how gifted people differ in their thinking from non-gifted people. It is described in terms of ‘richer and more complex knowledge structures in combination with meta-thinking skills’ (Gallagher, 2003), ‘enjoyment of challenges and complexity’ (Schiever & Maker, 2003), ‘better understanding of their own strengths and weaknesses’ (Sternberg, 2003), and ‘applying skillful thinking to perplexing problem situations’ (Costa, 2003).

To this day there is no consensus on one definition of giftedness.

Educating the gifted

A review study by Hoogeveen et al. (2004) shows that different educational adaptations all have both positive and negative effects. There is not one ultimate solution to gifted education. Good results for school achievements in many subjects were found when students were pulled out of the regular classroom, and were placed in a separate class or even a separate school for the gifted (ability grouping, tracking). Self-concept appeared to be affected in a negative way in these separate classes, however this is not necessarily a bad thing. It could be explained by the 'big fish, little pond' effect (BFLPE) (Marsh et al., 1995): one's academic self-concept depends not only on one's academic accomplishments but also on the accomplishments of classmates. If a student transfers from a regular class to a gifted class, he or she will not automatically be the smartest anymore, and therefore the academic self-concept can decrease, possibly to a more realistic level.

In the United States, grouping and tracking movements put up with a lot of resistance (Loveless, 1998, 1999). Adversaries state it is keeping schools from achieving educational equality (Kulik, 2003). In the Dutch educational system, "equality and equity are important characteristics. Its policy aims at striving for inclusion of all pupils" (Thijs et al., 2009, p.41). In secondary education tracking is widely spread in the Netherlands: VMBO, HAVO and VWO coexist.

This ambiguity is not only found in primary versus secondary school, it is also found in society as a whole. As Goh (1994) puts it: "it is paradoxical that a society valuing individualism, development of a unique identity, and individual rights, considers individualized education for the gifted as non-egalitarian."

Lately, more and more initiatives are taken to customize education for gifted learners. In primary schools part-time pull out programs or even full-time programs like 'Leonardo Classes'[2] are implemented. Some secondary schools profile themselves as a gifted profile school[3], and in higher education honor programs are initiated. But on the whole, on a national level, little policy has been developed yet.

When talking about gifted education, acceleration and enrichment seem to be the key words. Acceleration can be done within a classroom by deleting repetition, using the freed-up time for advanced content. It can also be done by allowing a child to skip a grade (or more). Enrichment means offering a student extra, challenging subject matter that is not part of the regular curriculum. Ideally enrichment activities focus on higher-order thinking skills. Kaplan (1979) and Clark (1988) propose problem solving as a starting point for developing enrichment subject matter.

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[2] Leonardo education originated in 2007 in Venlo and soon spread to the whole of the Netherlands. A Leonardo Foundation was founded. Its goal is to "realize tailored education for gifted students, in order to let them develop in a challenging environment, at their own pace and at their own level." Leonardo-students form special classes at a regular school. They are offered fulltime gifted education; a lot of emphasis is put on topdown teaching ("from the whole to the parts") and higher order thinking skills (deep level learning). Today there are 59 primary schools and 8 secondary schools with Leonardo classes. (Leonardo, 2011)

[3] In 2004/2005 CPS-group (Educational Development & Advice, Amersfoort) started a project, funded by the Dutch Ministry of Education, called 'GiftedProfileSchools' (BegaafdheidsProfielScholen). The goal of this project was to realize a nationwide network of secondary schools that offer high-quality gifted education. Today 22 schools are accredited. (BPS, 2011)

Acceleration can be combined with enrichment by using the freed-up time after deleting repetition for extra content beside or instead of advanced content. Many experts in the field of gifted education (VanTassel-Baska, 2000; 2003; Costa, 2003; Schiever & Maker, 2003) advocate this combination of acceleration and enrichment.

Research by VanTassel-Baska (2000) shows content acceleration is favorable in the core subject areas. After reviewing different educational models for gifted students (VanTassel-Baska, 2003), she advocates both acceleration and enriched learning. Furthermore she states that "the needs of gifted learners cut across cognitive, affective, social, and aesthetic areas of curriculum experiences" (p. 174). She introduces an Integrated Curriculum Model (ICM) which incorporates advanced content, higher-order thinking and a focus on real-world themes.

Costa (2003) focuses on thinking skills when putting together a curriculum for the gifted, along with "judiciously selected content" (p. 326).

Schiever & Maker (2003) refer to Thom's Catastrophe Theory when describing what they think to be proper gifted education: using both acceleration and enrichment, offering a gifted student increasingly more content up to the point where 'learning more' necessarily leads to 'learning differently'.

Good Practice: Design-based Learning

In the Bachelor program of the Department of Biomedical Engineering (BME) at the Eindhoven University of Technology, students are educated both by traditional courses and by means of an educational concept called Design-based Learning.

This Design-based Learning (DBL) consists of real-world (hospital) problems in which students apply the knowledge they obtained in courses, and in which they train their (engineering) skills such as experimenting, modeling, communication and cooperation. Since the start of the Bachelor program in 1997, DBL proved to be a very motivating and instructive way of learning. It developed through the years (see Appendix 1) to better suit the needs of the research field and to adapt to changing curriculum demands.

Design-based Learning combines Problem Based Learning with Cooperative Learning.

Cooperative Learning

Science is pre-eminently an area where people work together. For sure there will be some scientists who lock themselves in a room to work on a brilliant theory, but most researchers need each other to tackle today's problems. In multidisciplinary teams and (inter)national alliances they work cooperatively on the questions at hand. Even in after-school science activities like First Lego League (FLL, 2011) and the Dutch Eureka!Cup (EurekaCup, 2011) children work in small teams on science challenges.

The main researchers in the field of cooperative learning (CL) and the main advocates of this type of learning are Kagan (1994), Johnson & Johnson (1999; 2009) and Slavin (1999; 2004).

Kagan (1994) calls for positive interdependence, individual accountability, equal participation and simultaneous interaction in order for CL to be effective. Slavin encourages teachers to embrace this method since it is, according to him, “one of the greatest success stories in the history of educational innovation” (Slavin, 1999, p. 74). Why? “In many ways, cooperative learning was a success story in translating research into practice” (Slavin, 2004, p.2). Johnson & Johnson (2009) agree with him and say “its success largely rests on the relationships among theory, research and practice” (p. 365).

Cooperative learning was originally developed for heterogeneous groups in regular classrooms. The teacher constructs teams that each have some average, some below-average and some above-average achieving students. According to the inventors of this concept, CL is very suitable for above-average and gifted learners. There has been discussion about this among researchers (Matthews, 1992; Rogers, 1991; Sapon-Shevin, 1993), mostly based on observations and less on research, and mostly placing CL in heterogeneous groups opposite grouping/tracking. But why not take the best of both? Within the gifted group there is plenty of heterogeneity, once you start looking past IQ-scores (and even at them!) at personal experience and interests. Slavin himself states (1991) that cooperative learning can work within a completely tracked school. But, keep in mind:

> *Perhaps one of the greatest challenges cooperative learning poses for academically talented students concerns the extent to which cooperation is confounded with conformity. Working cooperatively with others is one valuable goal of schooling. Developing one’s personal identity and intellectual independence is another. School decision makers must keep both goals in mind as they set policies for teachers and students* (Robinson, 1991, p. 23)

Problem Based Learning

Problem-based Learning (PBL) originated in higher education; in 1969 it was introduced at the Department of Medicine at McMaster University, Canada. Since then it has progressed to many other medicine departments all over the world, and later on other graduate studies followed (Kuru et al., 2007).

In its original form PBL is a cyclic, iterative process consisting of three phases (Perrenet et al., 2000). Students are confronted with problems instead of facts and theories. Cooperatively, guided by a tutor, they decide what knowledge and skills have to be acquired and they proceed individually. In the final phase, together they try to figure out how to best use the learned material to solve the problem. The next cycle starts with a new problem definition.
This way PBL is used to acquire knowledge and to develop personal and professional skills.

Unlike regular educational practice, where exercises are clearly framed and most of the time have only one correct answer, PBL is about ill-structured problems that give students some degrees of freedom in approach and solution. PBL is more like the real world. Apart from solving the problem, students are also taught to define the problem first. This problem finding step, which is so important in daily life and in all professions, is often neglected in regular education. Gallagher et al. (1992) also found this problem-finding step to be significant and think it is “especially important since this is the component of problem-solving considered critical for creative productivity” (p. 199).

PBL teaches students to cope with problems and thus can be a great way to teach science, which is almost synonymous to problem solving. VanTassel-Baska (1998) thinks this way of learning enhances motivation of both student and teacher, it improves problem-finding abilities and it promotes intra and interdisciplinary learning.

Mioduser & Betzer (2008), after researching the use of PBL in a science curriculum for gifted children in Israel, found a significant increase in formal knowledge, a high overall performance of design skills and a positive change in attitude towards technology.

Building a science curriculum for secondary gifted education

If science is pre-eminently an area where people work together, shouldn’t we therefore be teaching our children how to work cooperatively? Could it even be the starting point of an educational model for teaching science to gifted children?

Science is almost synonymous to problem solving. Shouldn’t we therefore be teaching already to our secondary school students where to start and how to do this? And how to define a problem first? Could problem solving be a proper starting point for developing enriched subject matter?

Years of experience at Eindhoven University of Technology showed that Design-based Learning (DBL) is a joyful and effective way to teach science to university students. In this study we tried to find out if it could also be a joyful and effective way to teach science to gifted secondary school students. How do these younger students react to cooperative learning? How do teachers respond to this whole new way of dealing with the science subjects and with their students? Can we expect the same things here that we experienced at Eindhoven University? For instance:

- In spite of teacher training preceding the projects, teachers find it difficult to adjust to their new role: when to speak up and when to stay away from the students’ discussion? Some teachers find it very hard to stop explaining and start asking questions. And some teachers want to prevent the students from making mistakes, even though this is at the very heart of learning.
- Both teachers and students learn this DBL concept only by ‘trial and error’, and you get better at it every time you do it.

- It takes only a few weeks for students to 'get the hang' of this way of working. Once they know the drill, they arrange their own meetings and find their own research questions. They do want regular feedback on their accomplishments though, and they do need it too.

In short: can we translate Design-based Learning to a problem based, cooperative learning, science curriculum for secondary school gifted students?

Method

Research Design

Since secondary school is not university, and since 12-year-olds are not undergraduate students, some changes had to be made to the concept of DBL in order to adjust it to this target group: smaller project groups, less meetings per week and fourth graders instead of researchers to act as tutors. The key features of the educational concept remained as starting points though:

- Students learn to work cooperatively on real-world projects;
- The teacher is the overall coordinator of the project;
- Older students who act as tutors guide the younger students through the process;
- Projects are motivating to the students in terms of content, depth and width;
- There is not just one solution to the problem at hand and there is ample room for creativity;
- Students are urged to think and create, rather than reproduce;
- Plenty of time is allocated for experimenting;
- A lot of attention is paid to verbal and written reports.

Participants

The St. Willibrord Gymnasium in Deurne, The Netherlands, is a relatively small school of about 500 students. The gymnasium prepares its students for higher education at university. The Leonardo College (Leonardo, 2011) is a special class of gifted students within this school. It started with a first group of 15 students (14 boys and 1 girl) in September 2010. These 15 first graders came from very different backgrounds. Four of them were acknowledged as gifted in primary school. Two children attended Leonardo Primary School before enrolling the Leonardo College. One child took part in a gifted program at primary school consisting of one morning of 'plus class' each week. Another child received special attention from the teacher in his regular class. None of the others had any educational materials adjusted to their needs before.

Some of these 15 children already built up a lot of deception and frustration regarding school work, which they expressed to the class mentors on entering the Leonardo College.

The four science teachers who took part in this adventure had put themselves forward and were very motivated. They had backgrounds in physics, chemistry and biology. Although they were quite experienced with above-average students (the school being a gymnasium), they didn't have any experience with gifted groups in school, only the occasional gifted child in class. One of the teachers has gifted family members (husband, children, parents); none of the teachers thought themselves to be gifted.

Also the two mentors of the Leonardo students (both teachers) and the laboratory assistants showed a lot of interest in this project and joined in on (some of) the preparation and evaluation meetings.

The tutors were hand-picked by the science teachers and the mentors. They were fourth and fifth graders (Gymnasium consists of six grades), thought to be capable of handling a bunch of first grade gifted kids. Unfortunately, most of these tutors were themselves no 'beta-students', and most of them had no knowledge of, or experience with giftedness. They were very interested and motivated though.

Instruments

Before starting the science projects, all students and teachers involved were asked to fill out a questionnaire in which they were asked about their background and their expectations. During the project, the students were observed in the classroom and afterwards the lessons were discussed with the teacher involved. After each project the four science teachers evaluated it together. The students were asked to fill out a questionnaire again, focusing mainly on their teamwork-efforts and the guidance by teacher and tutors. After four projects, at the end of the school year, the teachers and the students were presented a final questionnaire.

Preparation & Planning

From March 2010 until the start of the school year in September 2010, preparations were made. Mostly these preparations consisted of briefing and training the teachers and the older students who were going to act as tutors for their new roles. And of course the content of the four projects was to be determined. The science teachers each took one project as their own, and used already known material from regular later grades to build their new first grade projects.

The four projects they put together were:

1. Experimentation: physics and chemistry experiments to get to know the set-up of the science projects, the classroom, the materials etcetera.
2. Matter: some basics about materials and a special focus on combustion; chemistry oriented.
3. Sports: about muscles, nerves and bones; mechanics & biology.
4. Water: biology oriented (plant stems, water creatures), but also some physics and chemistry (measuring flow in a ditch, filtering of pond water)

An attempt was made to put together a so-called ‘learning outcome matrix’, in which all knowledge and skills to be learned in this year by the students were spread equally over the four different projects. See appendix 3.

For each project 8 weeks were scheduled, with 2 contact hours a week. After that a new project, with a new teacher and new tutors, would start. Groups of 2 to 4 students were newly formed each time, sometimes by the teacher, sometimes by the students themselves.

With each project the students would receive a project planning and some background information on paper. Each week students would have to hand in their assignments.

Results

All student questionnaires consisted of both open-ended and closed-ended questions. The questions about PBL focused on science project set-up and the interaction between students and teacher/tutor. Questions about CL focused on ‘desirability’ and success. The teachers were asked mainly (in both questionnaires and verbally) about their expectations and preparation, and how they perceived the successfulness of their individual lessons and their project as a whole.

In tables 1 to 4 the answers are clustered for teachers and students.

Table 1a
Anticipating Leonardo College and the science projects – **teachers**

Questionnaire taken before the summer holiday preceding the school year 2011-2012	4 respondents
What will be your job next year?	teacher in regular class (4), Leonardo teacher (3), Leonardo mentor (1), coordinator ‘talent development project’ (1)
What subject(s) do you teach?	physics (1), chemistry (1), engineering (1), general natural sciences (“ANW”, 1), nature - life & technology (“NLT”,2)
What’s your experience with giftedness?	none (1), gifted child (1), gifted parent (1), gifted sibling (1), gifted spouse (1), gifted students (2)
What Leonardo-training (about giftedness) did you already attend?	Top Down Teaching (1), Deep Level Learning (2), Communication/Dealing with giftedness (1), none (1)
Are you enthusiastic about next year’s science projects?	not at all (0), moderate (0), a lot (4)

Do you think preparation time was enough?	a bit too short (1), just fine (2), a bit too long (1)
Do you feel well-prepared?	not at all (0), moderate (1), very (3)
What do you hope to achieve with the gifted students?	motivating the students for research and science (4), teaching the students to think (creatively) (2)
What do you fear or find difficult?	sufficiently challenge the students (1), define exact content for the project (1), get the students to work together (1), nothing (1)

Table 1b
Anticipating Leonardo College and the science projects – **students**

Questionnaire taken before the summer holiday preceding the school year 2011-2012	11 respondents
Did you attend Leonardo Primary School?	no (9), yes (2)
Did you attend a pull-out program in primary school?	no (8), yes (1)
Did you get special attention for being gifted in your regular class at primary school?	no (5), yes (1)
Do you like going to Leonardo College next year?	no (0), moderate (0), a lot (10)
What do you look forward to?	new subjects (5), other children like me (3)
Do you fear anything?	homework (4), languages (3), nothing (2), being new or alone (2)
Did you already have science education in primary school?	never (3), not often/few times a year (8), regularly (0)
Did you like these science lessons?	not at all (0), moderate (2), a lot (5)
Would you like to have science as a regular subject in secondary school?	not at all (0), moderate (2), a lot (8)
What science topic interests you most?	chemistry (6), solar system/universe (4), engineering (4), anything (3)

Table 2
Students' attitudes towards Cooperative Learning

	Start (13 respondents)	After & about project 1 (13 resp.)	After & about project 2 (9 resp.)	After & about project 3 (8 resp.)	After & about project 4 (10 resp.)
Clarity about teacher's expectation on teamwork in advance?		good (12) bad (1)	good (6) bad (3)	good (5) bad (3)	good (9) bad (1)
Cooperation during project		good (11) bad (2)	good (7) bad (0)	good (8) bad (0)	good (8) bad (2)
Do you prefer to work in a group or individually?	indiv.(2) group (11)	indiv.(2) group (11)	indiv. (0) group (9)	indiv. (0) group (8)	indiv. (1) group (9)
Specific comments (teamwork vs. individually)	<u>Group</u>: nice to divide tasks (4), more fun (4), learn from each other (1), depends on group composition (1) <u>Individually</u>: more control (2)	nice to divide tasks (3), success depends on group composition (2), fun (3), more ideas (2), help each other (3), slow because of bad cooperation (1)	fun (3), more / better work (3), more ideas (1)	good task division (4), more ideas (2), support each other (1), better cooperation than before (1)	good task division (3), not everyone in group contributed (3)
What would you like to change/improve?		choose group composition ourselves (1), group rules / cooperation (2)		rather duo than group (1)	group composition (1)

Table 3
Students' attitudes towards Problem Based Learning

	After / about project 1 (13 resp.)	After / about project 2 (9 resp.)	After / about project 3 (8 resp.)	After / about project 4 (10 resp.)
Did you enjoy this project?	no (1), yes (12)	no (1), yes (8)	no (0), yes (8)	no (0), yes (10)
Did you learn a lot?	no (0), yes (13), mainly: how to set up an experiment (8), how to report (5)	no (1), yes (7), mainly: what is chemistry about (3), combustion (3)	no (1), yes (6), mainly: about muscles (3), about nerve system (2)	no (2), yes (8), mainly: water filter (3), plant stems (2), measuring (3)
Information about project goals in advance	good (12), bad (1)	good (3), bad (6)	good (1), bad (6)	good (4), bad (6)
Teacher asked a lot of questions	no (4), yes (9)	no (3), yes (6)	no (3), yes (5)	no (1), yes (9)
Teacher gave a lot of answers	no (5), yes (8)	no (4), yes (5)	no (5), yes (3)	no (5), yes (4)
Teacher gave feedback on process	no (6), yes (7)	no (1), yes (8)	no (3), yes (5)	no (1), yes (9)
Tutor asked a lot of questions	no (11), yes (2)	no (5), yes (4)	no (5), yes (3)	
Tutor gave a lot of answers	no (8), yes (4)	no (7), yes (2)	no (5), yes (3)	no tutors on this project. Did you miss them? no (9), sometimes (1), yes (0)
Tutor gave feedback on process	no (7), yes (6)	no (5), yes (4)	no (7), yes (1)	
Best about project	experimenting (10), final exam (2), presentation (1)	experimenting (5), making firework (4)	field trip (4), final presentations (2)	experimenting (outside) (8)
What would you like to change/improve?	more experimenting (3), more help by tutor/other tutor (2), more time (2), no final presentations (1)	nothing (4), more experimenting (3), more help by tutor (1), more time (1)	more help by tutor (4), more experimenting (3), more explanation by teacher (3), more topics (1)	nothing (7), more time (1)

Table 4a
Final evaluation – **students**

Questionnaire taken at the end of the school year 2011-2012	10 respondents
What's the first thing that comes to mind about the science projects?	fun (3), experimenting (2), fireworks (2), field trip (1), laboratory (1), rather have more hours a week (1), water project (1)
Did the science projects live up to your expectations?	no expectations (3), expected more experimenting (2), expected more theory (2)
Next year, would you prefer teamwork on projects or traditional classical lessons?	traditional lessons (0), team projects (10)
What topics would you like to learn about next year?	don't know (3), chemistry (3), physics (1), biology (1), environment (1), universe (1), natural phenomena / weather (1)
Specific comments	"Some students should take this subject more seriously" "Science is cool!"

Table 4b
Final evaluation – **teachers**

Questionnaire taken at the end of the school year 2011-2012	4 respondents (all 4 Leonardo teachers)
Was this year easier or harder than you anticipated?	easier (0), just as anticipated (3), harder (1)
What did you like about working with the Leonardo students?	go deeper into content (1), small group (2), students' enthusiasm (1)
What didn't you like about working with the Leonardo students?	bad organizing skills (1), no self criticism / self reflection (2), behavioral and concentration problems (2), bad cooperation between students (1)
What was more difficult than expected?	motivating students (4)
What was easier than expected?	nothing (2), organizing presentations and demonstrations (1), group work (1)
In hindsight, were you well-prepared?	not at all (2), moderate (1), yes (0)

Are you enthusiastic about the set-up of your project?	not at all (0), it needs some improvement (4), very (0)
Next time, what will you improve?	training and use of tutors (4), more strict on homework (2), more structure in assignment (2), challenge students more (2)
Next time, would you prefer this project set-up or a more traditional classical style?	traditional classical (1), project (2), mixture (1)
What do you think about the level of cooperation between students during the projects?	Sometimes very good and sometimes very difficult, depending on the group (4)

This turned out to be anything but an easy year for the Leonardo teachers at St. Willibrord Gymnasium. They had high hopes and expectations for these gifted students and started out very enthusiastically. But soon they realized that it took a lot more effort to get these students in ‘school mode’ and get them to work and learn. The teachers had to reinvent their way of teaching and reset their hopes and expectations to a longer period of time: one year proved too short to reach all goals at once.

The problem based approach proved to be even more difficult for the teachers than for the students. A lot of the time the teachers fell back into the routine that was familiar to them: explaining instead of asking more deep level questions to get the students to find the answers themselves. The students were ambivalent: on the one hand they didn’t like this class teaching, on the other hand they were ‘lazy’ enough to just want the right answers and not do the work to find out for themselves.

Working cooperatively on the tasks proved to be sometimes difficult but desirable. At the end of the year, all students indicated they want to work cooperatively on projects rather than have class teaching or work individually on assignments.

The expected difficulties as described in the introduction were encountered in this year: teachers uneasy with this new style of teaching and students waiting for teachers to tell them what to do. But also the expected solution as described in the introduction was encountered: practice makes perfect. By the end of the year, both teachers and students were already getting better at Problem Based Learning and Cooperative Learning.

Discussion

The teachers complained most about the lack of dedication and willingness to work of these gifted students. Based on the different perceptions and definitions of giftedness, they had expected to get a class full of ‘eager-to-learn, question-everything, very-smart’ kids. Instead they got mostly ‘frustrated-with-school, intelligent-but-lazy, why-should-I-do-homework’ adolescents. The teachers literally found them to be “defensive and stubborn” since most students would ignore all instructions and advice. During the course of the year this improved quite a lot, but due to this negative attitude towards learning of most of these students, the teachers got the impression that they didn’t get as much done as they could have in a regular class. Question is of course if they really didn’t get that much done? At the end of this first year, the students are so much happier with school, they do express the willingness to learn and when the science lessons were really given in a problem based way with plenty of room for exploring, they actually showed some of the hoped for eager-to-learn, question-everything mentality. This shows that educational adaptations for the gifted do have positive effects on the learning and the attitude towards learning of gifted students.

The problem based approach proved to be even more difficult for the teachers than for the students. These teachers had been teaching their subjects for many years in a more traditional way, explaining to students step by step how to get to a solution of a very clearly defined problem. Now they had to let go of all of that, take a step back and put their trust in the students. But old habits die hard. A lot of the time the teachers fell back into the routine that was familiar to them: explaining instead of asking more deep level questions to get the students to find the answers themselves. However, most teachers expressed their belief in PBL as a great way to teach science, especially to gifted students.

The students were ambivalent towards the PBL method, especially at the start of the school year: they expressed a dislike for class teaching, but at the same time they waited to get all the right answers from the teacher instead of finding out for themselves. You could also say they were still stuck in the ways they were taught earlier in primary school, and they didn’t realize they now had the opportunity to explore. Often not until the end of the project, with the final presentation, did they get the true meaning and then they would have loved to do some more experimenting to find out ‘what if we …’. Then the true PBL spirit emerged, showing that also from a student’s perspective PBL is a great way to teach science.

Here also lies a task for the tutors and the teachers: they should ask more questions and give more feedback to the students. This year, working with tutors did not live up to its promise. Although the tutors didn’t have any experience with guiding groups of people (all they had was one day of training before the start of the project) this seemed not to be the biggest problem. For the most part it was due to the fact that the tutors were not confident enough with the content of the projects. They sometimes lacked basic physics, chemistry and biology knowledge, not being science-minded and not having had any content-oriented training by the teachers. They simply didn’t know what questions to ask to the first graders.

Sometimes it wasn't clear what the intended learning outcomes were for a specific project. For problem based learning to work, it should be evident for the students what is expected from them. But in this pilot year, the PBL-method turned out to be an experiment mainly for the teachers. They didn't know exactly what to expect from the students and so they sometimes failed to mention the learning goals to them. The 'learning outcome matrix' (see appendix 3), in which all knowledge and skills to be learned by the students is put down and spread equally over the different projects, was still only partially filled at the end of the year. This will need some attention in the following years, but experience from Eindhoven University learns that it will never be finished; it will always be a 'document under construction'.

Working cooperatively on the tasks proved to be sometimes difficult but desirable. At the end of the year, all students indicated they want to work cooperatively on projects rather than have class teaching or work individually on assignments. Even though they acknowledge the difficulties of being dependent on someone else and having to negotiate and compromise, they all say it is more fun working together and they like the fact they can divide the tasks. When asked what role in the team effort suited them best, most students mentioned the role of team leader. Most students also mention that they would like to have a vote on group composition. Both of these remarks indicate that the students like to have some control over the group as a whole, which might be because they don't dare to put too much trust in other team members yet. This is something to work on, for instance through a training on the value of different roles and individual input in teamwork. That way we also keep in mind Robinson's warning (1991) from the introduction: cooperative learning is a great tool for learning to respect other people's input, but it should leave room for personal growth and intellectual independence.

The tutors, getting better training and guidance by the teachers, should get a more active role regarding the cooperative learning than they had this year. Their feedback to the students on their performance in the group is crucial for the teamwork to succeed (Gómez Puente et al., 2010).

Even if the teachers' expectations of the beginning of the school year were not all met, this first year of gifted science education was still a success: the students were very interested in the topics and enjoyed learning about how to set up some small scale research. They sure loved the experimenting part of the science curriculum! During these experiments they were very focused and really tried to do a good job. The students could have done even better content-wise, had they had the right 'provocation' and the right questions asked by their tutors and teachers.

None-the-less, the teachers did a great job this year. With their enthusiasm for science and their concern and attention for the students, they succeeded in getting the students involved. It was expected from experience at Eindhoven University, that only by way of "trial and error" optimal results can be reached over a longer period of time. "It takes (much) more time than two years to transform a classical [university] education system into a student-centered education system, such as DBL" (Perrenet, 2001, p. 7). And Nebesniak concluded "there is no magic formula" (2007, p.34) when she described her attempts to implement cooperative learning together with problem solving in secondary schools.

Recommendations

The experiences lived up to the expectations when starting this study: even if teachers and tutors get proper training before starting their project, they find it very difficult and they learn most by doing. They (subconsciously) ignored a lot of pointers offered to them in the training, but then identified these same topics themselves afterwards as important for future development. In that way, it is problem based learning for them as well and they have a learning curve to follow. One teacher said, at the end of his project: “Just as I am beginning to get to know them, and know what to do with them, my project is finished. That’s a pity.” If the science lessons are to be given by multiple teachers, it is wise to allocate plenty of time in everyone’s schedule for meetings and visit each other’s classes. That way they can learn from each other and share good practices.

Teachers will also benefit from having a coach or a mentor, since it is very difficult to realize a fundamental change like this completely autonomous (Borko, 2004). Someone with experience from within school or someone on the outside that they can trust and with whom they dare to be vulnerable. It can be quite scary to let go of everything you have been doing in previous years and try something completely new in front of a class full of adolescents. The teachers will need someone they can go to with their questions and to share their experience with. Especially if it is a negative experience, since it is all too easy to quit if something doesn’t work right away. You need someone who, with support of the school board, keeps pushing you to go forward.

The tutors deserve more attention from the teachers. Preferably they are ‘beta-students’, but at least they should get proper training on the contents of the project. Or even better: do all of the experiments themselves before the project starts. That way they are more confident in the project and they can focus on bringing out the best in the students.

With the experience from this year, next year the projects can be defined in a more ‘problem based’ manner, with more room for creativity. Instead of giving the students information step by step, week by week, teachers can actually describe a real world problem, together with a project planning, books and websites for further investigation and a list of available materials for experiments. And then take one step back and let the students be smart and creative. Ask questions instead of give explanations. Challenge them to show their true giftedness. Let them make one giant leap forward.

Of course, all regular educational methods are still allowed in a PBL-setting, apart from the ‘student group sessions’. Teachers can make use of whole-class teaching, individual instruction, demonstration, guest lecture, field trip. But why not ask students to come up with a demonstration of an experiment, an interesting guest lecturer or an excursion as part of the assignment?

Maybe, in a few years time when the science content has settled a bit, some time can be allocated for creativity and creative problem solving (Treffinger, 2005). Often this is not thought to be a first priority, but surely it deserves some attention in a gifted curriculum, since this is exactly what we (teachers and society alike) expect from these great minds.

Over 10 years of experience from Eindhoven University tells us that for the cooperative learning to work even better, it is wise to have skills training for the students parallel to the projects. How to have an effective meeting? How to reflect on your own work? How to give feedback to your fellow group members? What are some different roles and tasks when working in teams? What role suits you best? This is also in line with the topdown teaching (see footnote 2, p.4) that the Leonardo Foundation advocates: explain to the students why they have to learn something and why it is done in this specific way. Of course, not only science would benefit from this skills training; it is also very useful in other subjects. So possibly this skills training can be scheduled during specific study counseling hours to take the load off the science hours. At the start of the year, the four science teachers were strong in their opinion that science was "a real subject, not a counseling hour", but in school of course all subject courses are counseling meetings as well.

It's wise not to give the students permission to divide tasks too much, because that way they learn less about the subject and about themselves. It is tempting for students to do what they already know, instead of stepping out of their comfort zone and learn something new. Perhaps they find new talents within themselves if they are obligated to execute all tasks. In the first year (or two), every student should do every task in every project. In later years, tasks can be assigned to the student who is best at it or wants to do it.

Some more thought can be given to the assessment. As Vleuten (1990) already pointed out, innovating an educational model without innovating the assessment has little chance of success. To prevent the students from 'free-riding' and to make sure students don't suffer the 'sucker-effect' (Robinson, 2003) both the combined efforts (the final product) and the individual efforts of each student must be appreciated. So one grade should be given to the group as a whole, a second grade should be given to each individual student. And teachers should be as strict with these students as they would be with 'regular' students. This year, being a pilot year, teachers were far too soft on the students. If a student doesn't put in effort, he or she should experience some consequences. This isn't harsh; students will also benefit from this. Finally something is expected from them and finally someone is waiting for them to deliver something 'real'.

Conclusion

This is not a one-year-success story but it turned out well. An educational transformation like this takes time, years even. Students have to learn to take a step up and take the opportunity to shape their own education. Teachers have to learn to let go and trust, to take a step back. Not all teachers are up for this. Some will not want to do it; some will not be able to do it, even with schooling and mentoring.

This raises a new question: Problem Based Learning and Cooperative Learning ask for different skills than traditional teaching. What makes for a good PBL/CL teacher for gifted students? That is a whole new research topic in itself.

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Appendix 1 Historical overview of Design-based Learning

Design-based Learning as a guiding educational concept[4]

On September 1st 1997, the rector announced at the opening of the academic year that Eindhoven University of Technology (TU/e) would start developing a new educational concept, called Design-based Learning (DBL for short).

By implementing DBL the university board aimed to enhance the quality of the undergraduate education. They also wanted to enhance students' professional skills and to intensify the relationship between research and education. Another goal of DBL was to push students towards more creative thinking and towards integration and application of knowledge, not just consumption of it.

Prof.dr. Wynand Wijnen, professor of Development and Research of Higher Education at Maastricht University and founding father of Problem Based Learning (PBL) at the Department of Medicine, was asked to further shape DBL.

Differences between DBL and PBL

With PBL, tackling a problem is a means to stimulate students to acquire and integrate knowledge. With DBL, students use and integrate knowledge that was offered to them in previous lectures and they get topic-specific information during special DBL-lectures. Focus is not so much on acquiring knowledge as it is on the process of problem solving and designing a solution.

Compared tot PBL, DBL has more of an engineering signature: plenty of time is allocated for experiments, simulation and modeling. The quality of the end product (which can be a prototype, a model, a protocol, etcetera) is taken into account by the coordinator when grading the project.

Key features of DBL[5]

- Professionalizing
- Activating
- Cooperative
- Creative
- Integrating
- Cross-disciplinary

[4] University Newspaper "Cursor" 41(17), 13 January 1999 and 42(26), 9 January 2000.

[5] Wijnen, W.H.F.W., Zuylen, J.G.G., Mulders, D.J.W.M., Delhoofen, P.J.W.M. (2000). Naar een nieuw evenwicht: Uitwerkingen van de zes hoofdkenmerken van ontwerpgericht onderwijs. *OGO-brochure nr.2.* Onderwijs Service Centrum, Technische Universiteit Eindhoven.

Students work cooperatively on projects (‘cases’), guided in the problem solving process by a tutor. Parallel to the projects, students are trained in engineering skills, societal skills and communication skills.

DBL at the Department of Biomedical Engineering[6,7]

The different Departments of the Eindhoven University of Technology took different roads in interpreting and implementing DBL. At the Department of Biomedical Engineering (BME), DBL evaluated from 12 short cases a year in 1997 to 4 longer cases a year in 2011 (see frame on this page). Both staff and students are very enthusiastic about DBL.

- The foremost important learning goal of DBL at the Department of BME is to learn to be critical about anything.

- From the beginning, a lot of focus was put on skills: a parallel skills training program was set up alongside the project cases, covering topics like ‘how to have a good meeting’, ‘how to present your results’ and ‘different roles in a group’.

- The themes of the cases have a close relationship with the current research topics in the department and present a good overview of the biomedical research field. Therefore the content is highly motivating for the students.

- The time allocated to each case (7 weeks) is ample to reach plenty of depth and create room for ‘real’ experimentation.

- Students meet twice a week with their group (consisting of either 8 or 4 students, depending on the project) for two hours at a time, in which they define the problem, plan a strategy and set self-study assignments for themselves. The time between meetings is filled with information gathering, experimenting, simulating and modeling. Halfway through and at the end of the project, students report (either verbally or written) to the case coordinator and to their student colleagues.

Historical overview of DBL at BME

1997	The new undergraduate program BME is the first to start with DBL. 4 cases each trimester (12/year). Tutors are not expected to be content-experts, ‘just’ process supervisors.
2001	evaluation shows more time is needed per case: switch to 2 cases each trimester (6/year) for first year students.
2002	also second year students switch to longer cases (6/year).
2003	pilot: first case in first year about the difference between school and university instead of a biomedical problem.
2005	this pilot is not a success: in the future all cases are to be about ‘real BME content’.
2005	after evaluation it is decided that all tutors need to be content experts as well as process supervisors, otherwise it is too difficult for them to guide the students to good results.
2005	successful pilot: third year students to act as tutors with the first case in the first year.
2006	switch to semesters with three blocks each; 3 cases per semester (6/year).
2006	peer review grade as a separate grade that needs to be sufficient.
2006	all feedback by tutors is stored in the ‘S-files’: a digital DBL file for each student.
2009	switch to 2 quarters per semester: 1 case per quarter (4/year).

[6] Sauren, A.A.H.J., Genderen, M.H.P. van (2002). Problem-based Learning at the Eindhoven/Maastricht BME Program. *Proceedings of the Second Joint EMBS/BMES Conference*, Houston, TX, USA, October 23-26.
[7] Self-evaluation Report 2005, Department of Biomedical Engineering, Eindhoven University of Technology, p.18-22.

- If necessary, extra lectures are scheduled in which a staff member or some external expert provides extra information regarding the topic.

- The tutors are chosen from the research staff of the involved research group. They are trained for their roles as process supervisors. Nowadays, PhD students who were themselves BME-students are the best tutors, since they know first-hand what a good tutor should or shouldn't do. The most important task of the tutor at all meetings is to ask questions (for example "are you sure this is an answer to your research question?") and to provoke the students. After each meeting the process is evaluated and students receive feedback from the tutor and from each other.

- At the end of each project, each student receives feedback and grades from their tutor, from the case coordinator and from their peers. Each grade has to be sufficient to pass the project. All feedback is stored digitally so that it can be used by the study advisor when talking to students about their progress.

Appendix 2 Interpreted quotes

The minds of learners must be fashioned and stretched in five ways that have not been crucial – or not as crucial – until now. … We must recognize what is called for in this new world – even as we hold on to certain perennial skills and values that may be at risk.
(Gardner, 2008, p. 11)

… if we believe that our programs should produce the next generation of leaders, problem solvers, and persons who will make important contributions to the arts and sciences, then does it not make good sense to model special programs and services after the *modus operandi* of these persons rather than after those of the lesson learner?
(Renzulli, 2005, p. 4)

If gifted students are to become leaders and professionals with the capabilities society wants and needs and/or self-fulfilled adults, their school experiences must prepare them to be effective solvers of undefined, real-life problems.
(Schiever & Maker, 2003, p. 169)

Appendix 3 Learning Outcome Matrix

The secondary school exit qualifications can be matched to specific knowledge and skills in each project.

For instance for the first science project “Experimentation: physics and chemistry experiments” (to get to know the set-up of the science projects, the classroom, the materials etcetera) these were thought to be:

Exit qualification	**Specific knowledge and skills in project 1**
A0 - Working Cooperatively	- Roles and tasks in a group - How to have an efficient meeting
A1 – Language	- Report findings to each other - Written report - Verbal presentation
A3 – Information	- Find a suitable experiment on the Internet or in books - Find the explanation for the observed phenomena
A4 – Instruments	- Execute the experiment with the appropriate materials
A6 – Research	- Execute the experiment as described - Record the results
A8 – Orientation on Study and Profession	- Science; Research
A9 – Reflection on Learning	- Teamwork versus Individual learning - Interest in science
B1 - Tables	- Report results by means of a table
B3 – The Influence of Science & Technology	- What is science?

This eventually leads to a so called learning outcome matrix, that shows where and how the different topics and skills are taught and tested in the curriculum.

	A0: working together	**A1: Language**	**…**	**A11**	**B1**	**B2**	**B3**
Project 1.1							
Project 1.2							
Project 1.3							
Project 1.4							
Project 2.1							
Project 2.2							
Project…							

there is no doubt that the talents of gifted children
need to be caringly and carefully nurtured.
With proper nurturing, the gifted and talented will
be better equipped to engage in the challenges
of solving global problems. Gifted children with
their curiosity, sense of humor, intellectual agility,
persistence in the pursuit of knowledge, originality,
independence, energy, nonconformity, intense
sensitivity, and even rebelliousness need our
understanding and encouragement. For them
gifted education is not a privilege; it is a necessity.
(Goh, 1994, p. 53)